

how it works



$R=0\Omega$; $I^2R=0W$ —no kidding!

Bill Travis, Senior Technical Editor

CERTAIN EXOTIC TECHNOLOGIES elicit the cynical statement, "It's five years down the road—and always will be." Until now, one of those technologies has been high-temperature superconductivity. Several real-world projects in the works at American Superconductor (www.amsuper.com) exploit the won-

ders of high-temperature superconductors (HTSs) in practical applications. Using a bismuth/calcium/copper-oxide/strontium/lead mixture in patented proportions, the company has succeeded in producing superconductors that operate at or above liquid-nitrogen temperatures (77K, or -196°C), with eminently usable current densities. High-temperature superconductivity has existed since 1986, when two physicists at IBM's research lab in Zurich, Switzerland, found that a class of compounds called copper-oxide perovskites exhibited superconductivity at temperatures greater than 77K. However, these compounds are brittle and cannot handle useful amounts of current. American Superconductor developed a bendable, high-current-density compound that's practical to produce in quantity.

To make a superconducting cable, the company surrounds a central tube (through which liquid-nitrogen coolant flows) with metallic-like strips of HTS material, wound diagonally (Figure 1). Layers of thermal and electrical insulation surround the HTS layer, and a steel-jacket binding ensures the integrity of the assembly. In cooperation with Pirelli Cables and Systems, American Superconductor is nearing completion of a project to replace copper wires in an existing system. Three 400-ft HTS cables

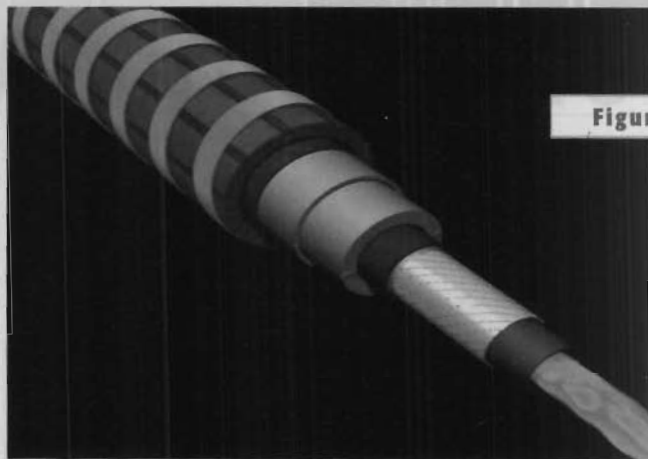


Figure 1

A high-temperature superconducting cable consists of an inner tube for liquid nitrogen, superconducting ribbon, and various insulating layers.

will replace nine copper cables in Detroit Edison's Frisbie substation; 250 lbs of HTS wire will carry as much current as the 18,000 lbs of copper it replaces. Moreover, the project will free up six cable ducts for possible use in meeting future load growth. This first large-capacity superconducting line will begin operation in mid-2000. The line will demonstrate the practicability of large-scale superconducting power transmission and will ostensibly be the first of many such lines.

Perusing the data sheet for a typical American Superconductor product is an interesting experience. One looks in vain for a resistance spec, because at temperatures at or near 77K and at current levels below the specified critical current, *there is no resistance*. Bi-2223 multifilamentary wire comes in two sizes, with cross sections of 0.168×3.1 and 0.203×4.1 mm. The critical currents (above which the wire becomes resistive) are 62 and 100A, respectively. Maximum current density for both sizes is 12 kA/cm^2 . The company has reported density as high as 70.5 kA/cm^2 in recently developed products.

In the beginning of the 1990s, usable current density in high-temperature superconductors was near zero.

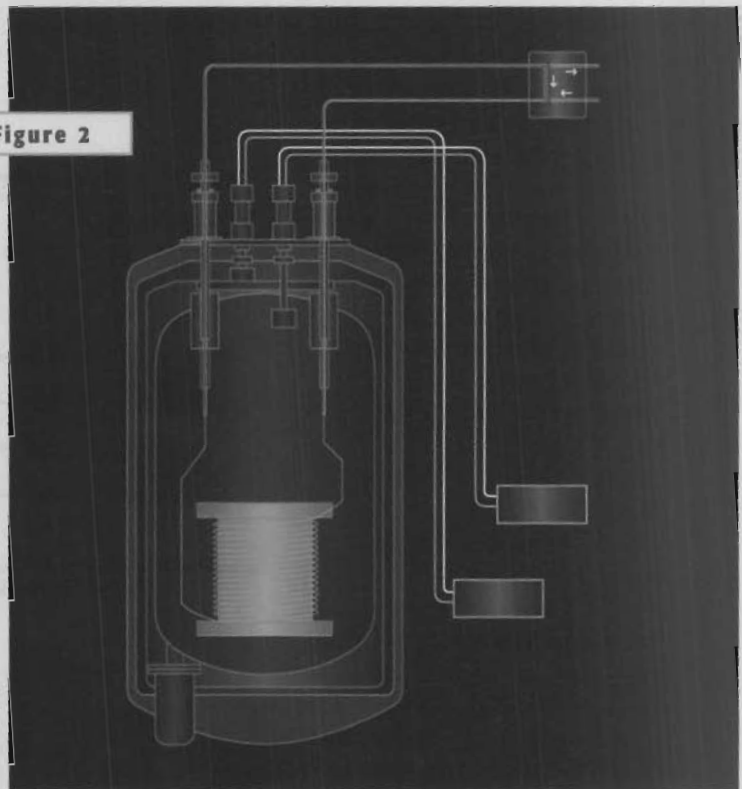
According to John Howe, American Superconductor's vice president of electric-industry affairs, a major problem the power industry faces is not just a continuously growing load demand but the need for *quality* power. For many consumers of power, a momentary sag in voltage levels is not merely an inconvenience; it can be a disaster. In a continuously running production process using induction motors, for example, a short sag in voltage can trip protection devices and shut down the line. For many processes (for example, paper production), a shut-down can be catastrophic, leading to belt breakage and other woes. Power sags can cost manufacturers tens of thousands of dollars in damage and production downtime for each event. For this reason, American Superconductor is producing the superconducting magnetic-energy-storage (SMES) system. The system is designed to prop up the line voltage when sags occur.

An SMES unit uses both low-temperature superconductors (LTSs) and HTSs (**Figure 2**). The magnet coil shown stores 2.7 MJ of energy and can inject 1.7 MVA to restore a sagging line. The system uses liquid helium (at approximately 4K) as a coolant and titanium/niobium superconducting wires for the magnet. Though liquid helium is nominally approximately 15 times as expensive as liquid nitrogen, it's a cost-effective coolant in the SMES system. The rectangles at the right of the assembly represent the recondenser (the main body of the tank) and the coldhead (the outer jacket) compressors for the liquid helium. The refrigeration process consumes only approximately 18 kW. The leads from the magnet to the outside of the tank use HTS material from American Superconductor. The HTS material accomplishes two goals: It drastically reduces electrical losses over earlier SMES systems that used copper conductors, and it greatly cuts thermal losses through the high-thermal-conductivity copper.

The block diagram in **Figure 3** shows the operating principle of the SMES. If the sensing-and-control block detects a sag in the line voltage, the SMES dumps the magnet's energy into the 14,000- μ F capacitor bank. The capacitor bank drives a dc/dc converter that provides a suitable input to the dc/ac inverter. The insulated-gate bipolar-transistor-based, 1.3-MW three-phase inverter converts its dc input to an ac voltage suitable for phasing into the sagging line. A monitor system records the three-phase voltage and current waveforms during events in which the SMES props up sagging lines. In addition to fixed SMES systems, American Superconductor has developed distributed-SMES (D-SMES) units, which

are trailer-mounted systems that can connect to grids at substations. Power companies can add, remove, or relocate D-SMES systems in response to changing grid conditions. An SMES system recharges within minutes and can repeat the charge/discharge sequence thousands of times without degradation of the magnet.

As stated, superconducting technology is here now. American Superconductor is collaborating with Wisconsin Public Service Corp, installing several D-SMES stations in a new 250-mile, 345-kV line from Duluth, MN, to Wausau, WI. Six SMES units



A superconducting magnetic-energy-storage system uses a superconducting electromagnet to store several megajoules of energy, which you can inject into the power grid during voltage sags.

at five locations will supply 2.8 MVA of continuous support, with the added capability of a 100% over-current condition for 1 sec. Network analysis of the proposed power grid indicates that voltage sags of 50% are possible under adverse load conditions. The performance criteria of the D-SMES system are that the system recovers to 90% of nominal voltage within 0.5 sec and to 95% within 5 sec of a triggering event. Under another contract, American Superconductor will install an SMES system at a leading (unnamed) semiconductor manufacturer in the United States. Ostensibly, the cost of manufacturing

downtime in semiconductor fabrication from momentary drops in voltage is enormous.

Power cables and SMES systems are not the only applications for superconductivity. American Superconductor is working with Reliance Electric to develop motors that use HTS rotor windings. A 1000-hp motor is now a reality, and a 5000-hp behemoth is slated for later this year. Looking further into the future, American Superconductor is under contract with the US Office of Naval Research to design a 25,000-hp ship-propulsion motor for future Navy ships. A conventional 25,000-hp ship-propulsion motor is approximately the size of a city bus; the HTS model is expected to be approximately the size of a sport-utility vehicle. HTS-based motors have approximately half the size and weight of copper-wound motors and use 1 to 2% less electricity. In a 10,000-hp motor, this power saving could amount to \$100,000 per year.

Transformers can also benefit from the advantages of superconductivity. American Superconductor is collaborating with Asea-Brown Boveri (ABB) and Électricité de France in the development of HTS-based transformers. HTS brings three benefits to transformers. First, size and weight decrease by a factor of two. That decrease is a major consideration, because a 40-MVA transformer can weigh 100 tons. Second, the lower (0Ω) winding resistance leads to lower losses and higher conversion efficiency. Third, liquid nitrogen is inert and envi-

ronmentally harmless, unlike the oil normally used to cool and insulate transformers. In an ongoing project, American Superconductor is collaborating with ABB and Air Products and Chemicals Inc to develop and install the first HTS transformer, rated at 10 MVA, in a US utility network. Los Alamos National Laboratory will provide special characterization of the HTS wires and components used in the project.

Finally, HTS conductors are useful as fault-current limiters. They act something like a polymer fuse or a PTC-ceramic limiter, in that they exhibit a sharp increase in resistance above a certain threshold current level. An HTS limiter works on the principle that, above a certain critical current, it loses superconductivity and becomes resistive. The beauty of the device is that, under normal conditions, it exhibits no I^2R heating and no voltage drop.

The described projects and others show that high-temperature superconductors are not merely laboratory curiosities. This year and next year will witness the ribbon-cutting ceremonies of several large projects involving power grids, large motors, and giant transformers. In anticipation of the demand that will ensue, American Superconductor is gearing up for large-scale production of HTS wire and the products that use it. Both the availability of miles of superconducting cable and cost reductions through economy of scale promise to expand the current applications of HTS and open new applications. □

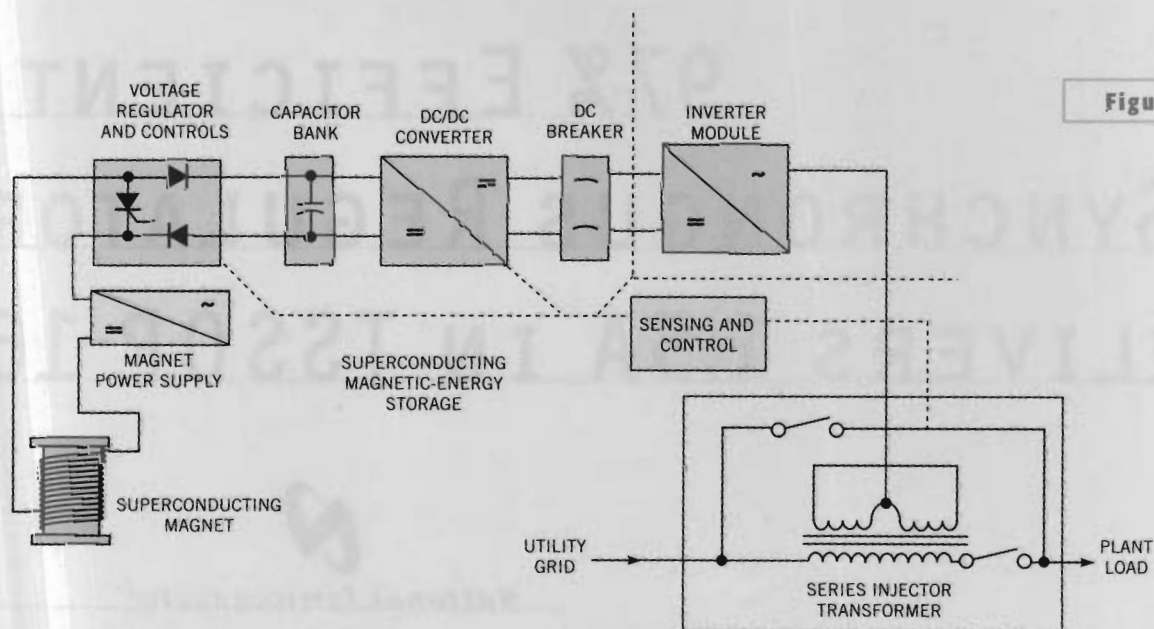


Figure 3

The various blocks in this diagram fill half the trailer of an 18-wheeler. Distributed superconducting magnetic-energy-storage systems are transportable to respond to varying power-grid demands.

name that widget!

Enter our
contest and
win
BIG!

winners!

From our Nov 11, 1999, contest

FIRST PRIZE: \$100

Jim Lemery, Precision Interconnect

When your Web browser grinds to a halt after choking on all those bandwidth-robbing banner ads, you need to get out of the way of everyone else's whizzing data packets. And, to make sure those whizzing data packets don't hit you, you need the widget from our November 11 contest. It's a road flare for the information superhighway, says Jim Lemery, a fact that should be intuitively casual to the most obvious observer. Just look at those sparks spewing forth from that copper cable! Jim takes the \$100 prize for correctly (sort of) identifying a widget that, surprisingly, mystified everyone else.

Of course, Jim's "sort of" correct identification isn't the really correct identification provided by the widget's manufacturer. According to Coilcraft (www.coilcraft.com), the widget in the picture isn't the copper cable itself, but the tiny power inductor on top of it. The DO1813HC series inductors have rms current ratings from 0.72 to 6A, inductance values from 0.56 to 48.1 mH, and dc resistance as low as 0.01V.



No, the widget from our November 11 issue isn't a road flare for the information superhighway. The device on top of the sparking cable is actually a Coilcraft power inductor.

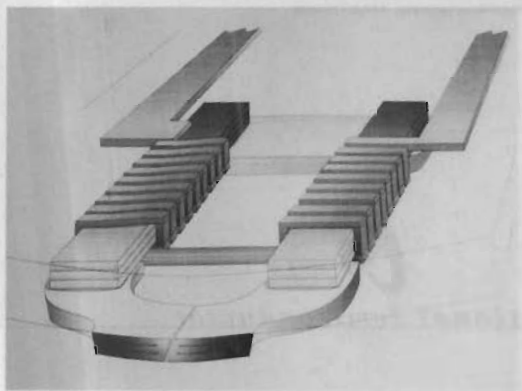
RUNNERS-UP

A millennium-edition Y2K 2-kV Van de Graaff Christmas-tree topper.—Alec Bath, Waferscale Integration Inc

For compatibility with flow-powered cleaning devices, this device will force toilets in South Ameri-

ca and Australia to flow in the clockwise direction.—Bob Belcher, Wave Mechanics Inc

A miniature hairball remover for cats. Just shove the end down the cat's throat, and it attracts the ball. Then pull it out.—Bob Thompson, Coverter Concepts



Name this widget and win \$100.

Show some *flair*, not *flare*, in our latest widget contest and win \$100 to start the new millennium in style. You could even use the prize money to pay for a DSL or cable connection and let those banner ads come through without slowing you down. Suggest a name or purpose for our newest widget that will *spark* laughter in Wally Widget's heart. Send your entry (or entries), along with the issue date, by e-mail (widget@edn.cahners.com), by fax (Wallace P Widget, 1-617-558-4470), or by snail mail (Wallace P Widget, EDN, 275 Washington St, Newton, MA 02458). Tell us what you think the mystery widget is. Don't tell us what it *really* is; tell us what it *could* be. We'll publish the winning entry and some witty and amusing honorable mentions in an upcoming issue. We'll also identify the manufacturer and tell you the device's real purpose. Please supply an e-mail or mailing address so we can notify you if you win.